Astrophysics

The Structure of the Solar Nebula

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The coplanarity of the planets in our solar system suggests that they all formed from a flattened gaseous nebula which has since dispersed (the "solar nebula"). The existence of similar protoplanetary disks in other systems has recently been confirmed by Hubble Space Telescope observations which show flattened nebulae in silhouette against the hot background of the Great Nebula in Orion. Many of the disks observed there are probably being eroded away by radiation from the massive, bright stars that illuminate the nebula and so will never form planetary systems (see also in this report the paper by Hollenbach et al.). Nevertheless, their direct observation confirms that solar nebula analogs and thus planetary systems may be common. This report describes recent research into the structure of the solar nebula which suggests that planets may have formed in darker, colder environments than generally believed.

Even with direct observations of solar nebula analogs, numerical and analytic models must be used to determine conditions deep inside at the planet-forming midplane. Work has been continued in this field by deriving temperature and density profiles for a variety of possible protoplanetary disk phases. The models encompass early solar nebula analogs appropriate for times when material spiraled rapidly in through the disk to land on the young Sun and the disk was thick and dominated the radiation emitted from the systems, to later analogs in which the flow of material was small and the disk was thin and energetically less important. The models also consider systems in which the stellar mass is larger or smaller than the mass of the Sun so that it will be clear which differences are a result of real variation in mechanism and which are merely a result of the differences in the stellar mass of the central star. One of the key conclusions made (along with collaborators T. Henning and H. Klahr of the University of Jena, Germany) was that throughout most of the lifetime of the disk and throughout much of its radial extent, the disk surface is shielded from radiation by the central star.

Because of a lack of detailed models, it has often been assumed that disks are either essentially flat or curve continuously upward so that their surfaces are illuminated everywhere by light from the central star. Detailed studies, however, show that the shape of the disk's surface is controlled by the local temperature-dependence of the opacity. Because the opacity diminishes at lower temperatures, the disk becomes more optically thin as one moves radially outward, and the thickness of the disk decreases. Inner annuli thus shield outer annuli from stellar radiation. At early times, when mass flow through the disk was large and local energy generation strong, this was probably not a large effect. At later times, however, when planet formation is thought to have been most important, a cooler environment may have shortened the timescales of planet formation by enhancing the effect of self-gravitation in the coagulation of micron-size dust particles into macroscopic bodies or by decreasing the relative velocities between planetesimals themselves, thus allowing for speedier assembly into protoplanets.

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